Manufacturing Engineering

Year 1

SECTION 1

UNDERSTANDING MATERIALS

MATERIALS FOR MANUFACTURING

Classifications of Materials

Introduction

Dear learner, in this section you will learn about the connection between materials science and engineering and its relevance to technological advancement. The chapter focuses on material science, which studies the composition, structure, and properties of materials, leading to the creation of specialised materials for modern applications. The growth of societies is closely tied to how people manipulate materials to meet manufacturing needs.

Materials engineering emphasises the design, development, processing, and practical use of materials to address real-world challenges. You will explore how the structure, processing, and properties of engineering materials affect their performance and use. Understanding these aspects aids designers and engineers in selecting appropriate materials for new products or repairs.

Finally, the chapter discusses how the application of materials across various industries depends on their characteristics and suitability for specific tasks, considering factors such as thermal, chemical, and mechanical resistance, as well as ease of manufacturing and durability.

At the end of this section, you should be able to:

- Explain the relationship between material science and engineering.
- Explain that the structure, processing, and properties of engineering materials affect their performance and use.
- Distinguish between different kinds of materials.
- Group materials based on their industrial applications i.e., clothing, building, food, automobiles, electronics and medical.

Key Ideas

- Material science is the study of the properties, structures, processing, and performance of materials. Material engineering uses knowledge to select, create, and design new materials with novel properties or enhance the properties of existing ones.
- An important aspect of material science is the knowledge of the structural arrangement of its atoms and how these structures can be changed by some processing techniques. The properties of the engineering materials depend on the original structure or the induced structure.
- Materials used for manufacturing can be grouped into metals and non-metals. Metals differ from non-metals in their appearance and physical behaviour. Knowledge of these properties is useful in making engineering decisions. Materials such as aluminium,

copper, and steel are classified as metals, while others such as plastics, ceramics, and composites are classified as non-metals.

- The choice of material for a particular purpose or task in various industries largely depends on its characteristics, such as chemical, physical, and mechanical properties and suitability. Every industry has specific materials suitable for its application. This is obvious in the clothing, building, food, automotive, electronic, medical, and healthcare industries.

HISTORICAL BACKGROUND OF MATERIALS

The development of societies is influenced by the ability of humans to produce materials that meet their needs. Civilisations have been marked by the development of materials such as the Stone Age, Bronze Age, Iron Age, Steel Age, Space Age, and Electronic Age. Initially, humans had access to naturally occurring materials like stone, wood, clay, and skins. Techniques for developing improved materials led to pottery and metals. Heat treatment and alloying increased the range of materials available. In recent times, scientists have developed materials with specialised properties, such as metals, plastics, glasses, and fibres, which have led to the development of modern technologies. Semiconductor materials are used in electronic devices like phones and computers. The discovery and development of advanced materials, biomaterials, and smart materials have revolutionised all industrial sectors, responding to human needs and producing efficient responses.

Material Science

Material science is an interdisciplinary field that involves the investigation and innovation of materials. It includes the study of the relationship that exists between the structures and properties of materials and how to use this knowledge to enhance the properties of existing ones or to create new products.

People who work in the field of material science are called material scientists. They engage in research and development activities to discover new materials and improve existing ones. They also perform scientific tests to analyse and understand the properties of materials. Additionally, they design materials with specific properties for special applications such as high-speed electronics, advanced medical devices, sustainable buildings, and many more. The development of lightweight materials for use by vehicles can lead to fuel efficiency and reduce greenhouse gas emissions.

Global plastic waste problems can be addressed by developing and using value-degraded materials. Biomaterials have great prospects for changing the phase of medical science by providing safe and compatible materials to replace worn-out tissues and organs. Flexible and wearable electronic devices are fast replacing conductive materials in the electronic industry due to the innovation of material scientists.

Material Engineering

Material engineering is concerned with the practical design and development of materials with desired properties and functionalities for specific applications. It focuses on ensuring that the properties of materials are tailored towards meeting specific mandates to solve real-life problems by making materials stronger, lighter, durable, or environmentally friendly. The main roles of materials engineers are to design and develop entirely new materials with novel properties or to improve existing ones. They test the properties of materials under various conditions to ensure they meet the required product specifications and scale up production for industrial and commercial use.

Materials engineers play a critical role in technological advancement and improving the quality of life. They design and develop materials with unique properties to meet human needs. For example, they create materials for medical implants and devices that enhance healthcare, improve the safety and performance of vehicles, develop flexible electronic materials, and create materials that increase the efficiency of energy production and storage systems. All these advancements are made possible with the expertise of materials engineers.

Relationship between Material Science and Engineering

Both materials science and engineering are characterised by four basic principles: processing, structure, properties, and performance. These four components are interrelated. Thus, the structure of a material depends on how it is processed, whereas a material's performance is a function of its properties. This relationship is demonstrated in Fig. 1.1. Performance is how good a material is based on its properties. Properties also describe some macroscopic features such as hardness, elasticity, thermal conductivity, electrical conductivity and density of the material. These properties are mainly determined by a material's structure. Structure is the feature of a material operating on different length scales. Structures could be seen with the naked eye or as small as an atom. Some examples of structures include grain boundaries, grain orientation, crystal structure, and atomic structure. These structures are often influenced by the processing of the material. Processing is the procedure used to create a material. This usually includes heating, melting, grinding, cooling, and quenching to influence the structure of the material.

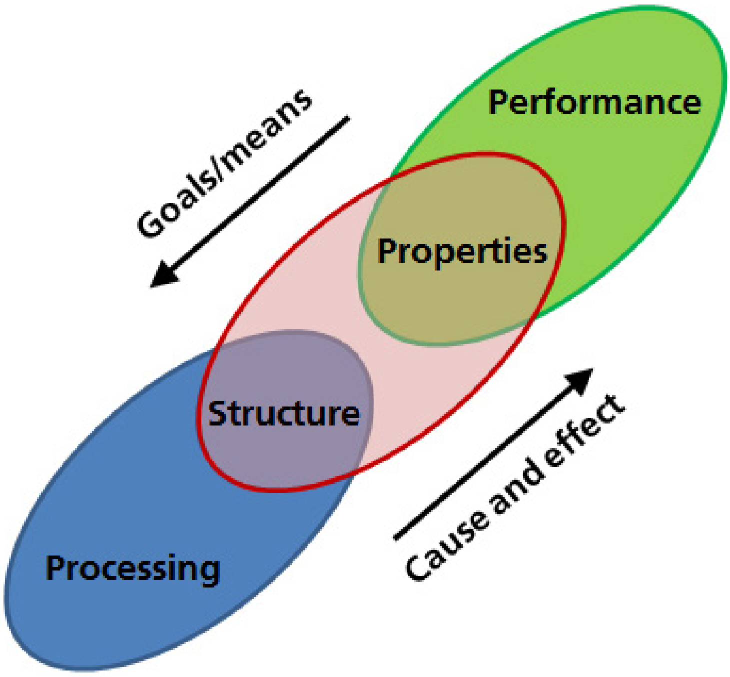


Fig. 1.1: The Basic Principles of Engineering Materials

All four basic principles of materials are greatly influenced by the goals that the materials scientist or engineer aims to achieve as they progress through each principle. Materials scientists or engineers can also consider manipulating the material using a cause-and-effect analogy as they move along the chain. Thus, the final performance of the material depends on how the processing is carried out to obtain a particular structure and its associated properties, which ultimately benefit its performance.

Importance of Studying Material Science and Engineering

Most design problems revolve around the ability to select the right material that is both suitable and user-friendly from the vast array of available options. The final decision is typically based on several criteria, including in-service conditions, material properties, and cost. The study of materials science and engineering will help you to:

1. **Select a material for a project:** Gain the knowledge to choose the most appropriate material that meets the specific requirements of your project, ensuring optimal performance and durability.
2. **Compare materials based on cost and performance considerations:** Develop the skills to evaluate and compare different materials, considering both their cost and performance, to make informed decisions that balance budget constraints with functional needs.
3. **Understand the limits of materials and the change of their properties with use:** Learn about the limitations and potential degradation of materials over time, helping you predict and mitigate issues that may arise during their service life.

4. **Create new materials with desirable properties:** Acquire the ability to innovate and develop new materials tailored to specific applications, combining desirable properties to meet emerging challenges and needs.
5. **Use materials for different applications:** Enhance your versatility by understanding how to apply various materials across different contexts and industries, ensuring that you can adapt to a wide range of design and manufacturing scenarios.

Activity 1.1

1. Search the internet or watch the video on the history and evolution of materials using the link below:

2. Collect materials from your communities or surroundings and group them into raw materials and processed materials. Match these materials using mappings.

   For example:
   - Wood (raw material) ⟶ Wooden plank (processed material)
   - Cotton (raw material) ⟶ Fabric (processed material)

3. Now, organise and categorise the materials you have collected accordingly.

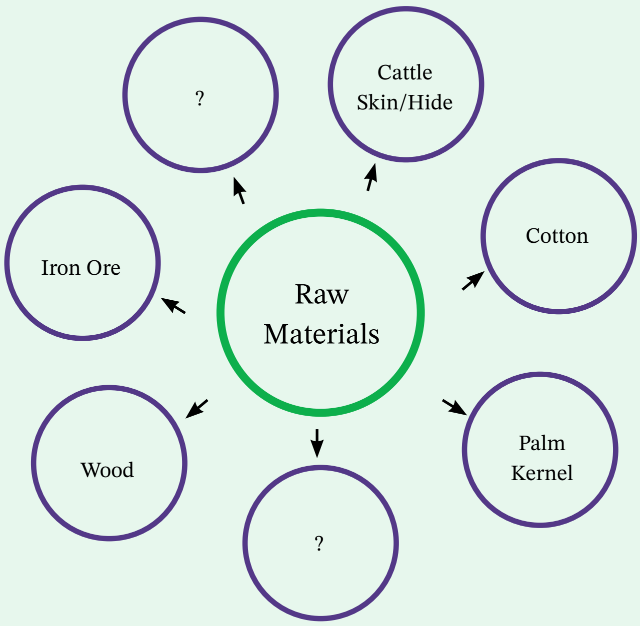


Fig. 1.2: Examples of raw materials

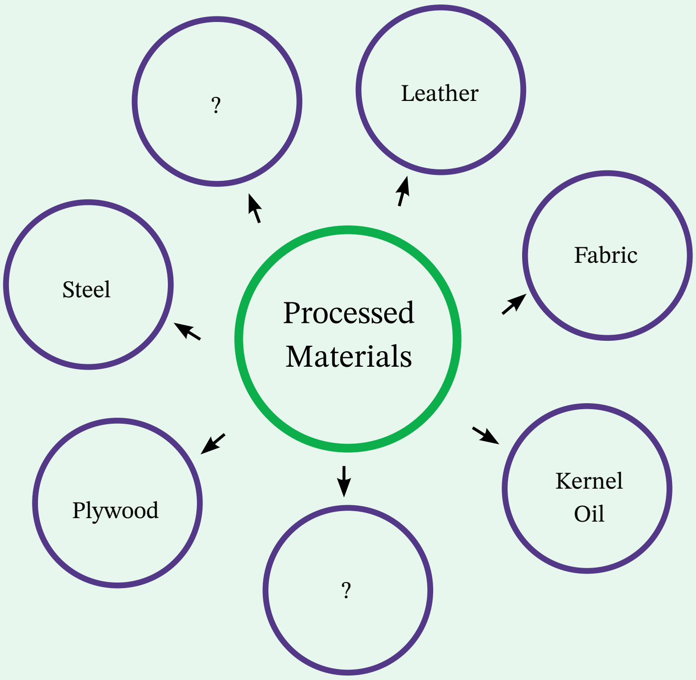


Fig. 1.3: Processed materials of Fig. 1.2

4. Now, following the example above and your understanding, list eight (8) more materials under raw and processed categories

Extended Reading

1. Callister, W. D., & Rethwisch, D. G., (2020). *Materials Science and Engineering: An Introduction*, 9th Edition, John Wiley & Sons. Chapter 1
2. Tiwari, A., Murugan, N. A., & Ahuja, R. (2016). *Advanced Engineering Materials and Modeling*. John Wiley & Sons.
3. Donahue, C. J., (2019). *Reimagining the materials tetrahedron,* Journal of Chemical Education, 96, 12, 2682–2688.

THE STRUCTURE, PROCESSING, AND PROPERTIES OF ENGINEERING MATERIALS AFFECT THEIR PERFORMANCE AND USE

In this lesson, we shall learn about the structure, processing, and properties of engineering materials.

Have you ever used a material at home or school and wondered about its performance? Understanding how engineering materials work is crucial for selecting the right ones for specific tasks. The suitability of an engineering material depends on its original structure, how it was processed, and its properties. Processing methods affect the material's structure at microscopic (viewed under a microscope) and macroscopic (visible to the naked eye) levels.

Knowing the structure and properties of materials helps designers, engineers, and technicians choose the best materials for their designs. It also guides them in selecting materials for manufacturing new products or repairing existing ones. This understanding ensures that materials perform effectively in various applications.

Structure of a Material

Most engineering materials fall under the category of solids when it comes to the classification of matter. Every matter consists of unique atoms or crystals (lattice cells) that are arranged in a particular manner that does not change unless some energy or treatment is applied to it. This pattern of arrangements of atoms or crystals is usually repeated within the entire material, and it dictates the properties of that material.

The structure of a material is the arrangement of its internal atoms that are repetitively arranged within the entire material, and it predicts the properties of the material. The structure of a material could be classified in the following ways:

1. Atomic structure (structure seen with a mass spectrometer),
2. Crystal or lattice structure (structure seen with X-ray crystallography),
3. Microscopic structure (structure seen under a microscope), and
4. Macroscopic structure (structure seen with the naked eye).

Atomic Structure

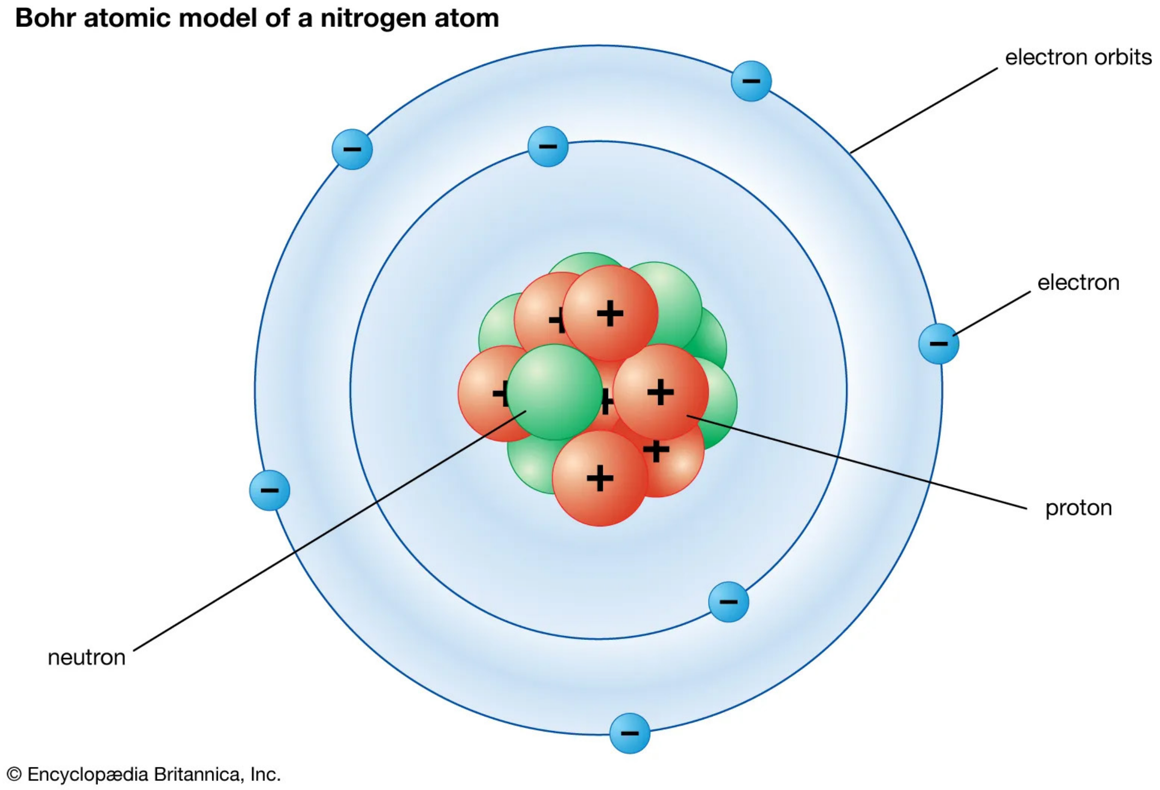
The atomic structure is the fundamental structure of every material. It consists of the nucleus surrounded by electronic orbitals, as shown in **Fig.1.4**.

This structure could be changed by some techniques, such as:

a. **Exposing material** to intense light (a laser beam). This is done by delivering intense energy to the material in a controlled manner to modify the atomic structure.

b. **Ion implantation** is the doping of a base material with a foreign material, where ions of a desired element are accelerated to high speeds using an ion accelerator. The accelerated ions are then directed towards the surface of the target material. This process modifies the atomic structure of materials such as semiconductors.

c. **Ion irradiation** involves bombarding the material with energetic particles to introduce defects and modify the atomic structure of materials such as nuclear materials.



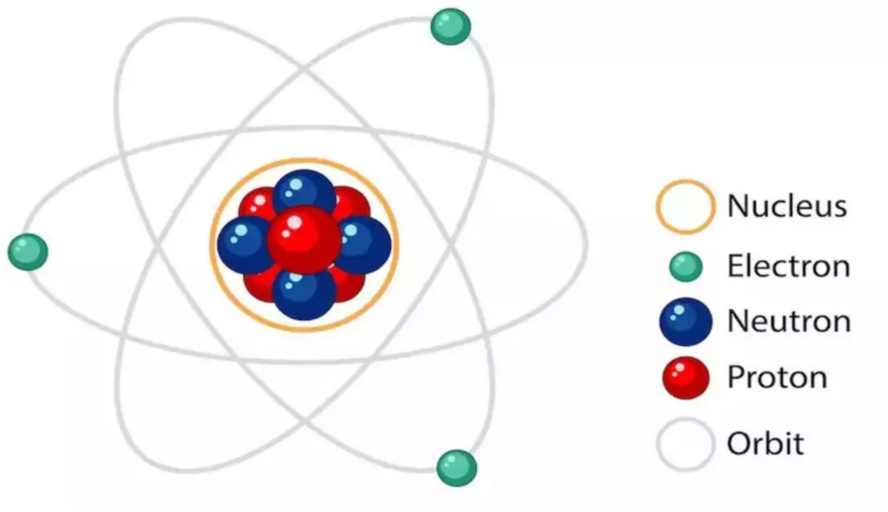


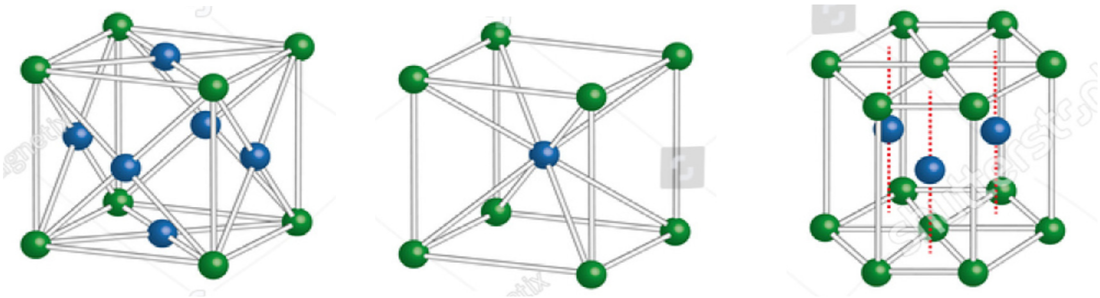
Fig. 1.4: Atomic structure

Crystal Structure

The crystal structure of a material is composed of several atomic structures held together by interatomic bonds or intermolecular bonds, depending on the material. It is the arrangement of the atoms, ions, or molecules of a material in a regular, repetitive pattern in a three-dimensional space. Figures 1.5 and 1.6 show the typical crystal structures of some materials. Figure 1.5 gives the single (reduced) crystal structures of materials, while Figure 1.6 shows the aggregate crystal structures of the respective materials.

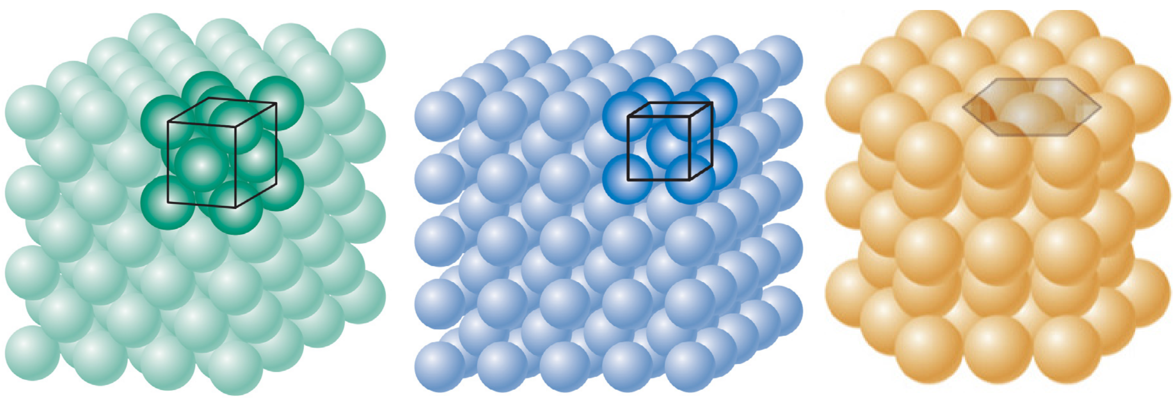
The crystal structures of materials can be changed by some of the following techniques:

a. Extreme heating of material.
b. Applying extreme pressure (impact load or severe hammering) to deform the material.
c. Applying a laser beam to the material.



Face centred cube Body centred cube Hexagonal centred crystal cube

Fig. 1.5: Crystal structures of some materials – simplified crystal structures



Face centred cube Body centred cube Hexagonal centred crystal cube

Fig. 1.6: Crystal structures of some materials – the respective aggregate crystal structures

Microscopic Structure

It is the structure of the material as seen under the microscope. Figure 1.7 shows typical microscopic structures of some materials at high resolutions under the microscope, while Figure 1.8 shows the microscopic structure of a material at a low resolution. A metal's microscopic structure reveals the detailed arrangement of its constituents at a very small scale. This structure is primarily composed of individual crystalline grains, each with a periodic arrangement of atoms known as the crystal structure (lattice).

Examples of the microscopic structure of some metals at high resolutions

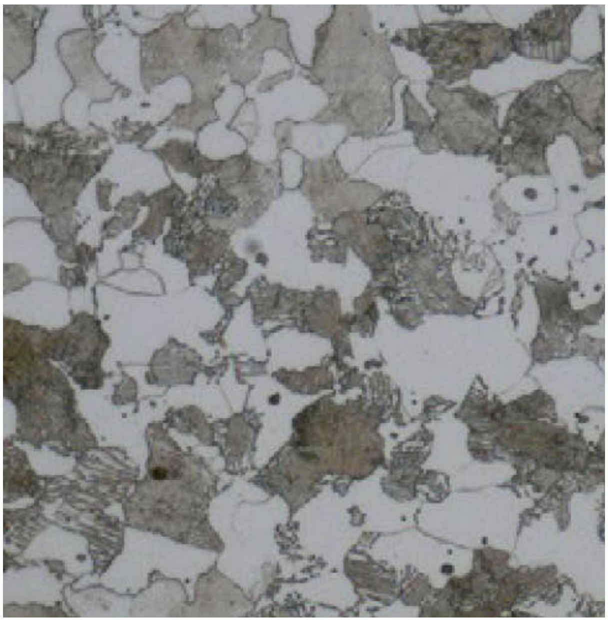


Fig. 1.7: Steel (*Ferritic-pearlitic steel) at* 50 µm

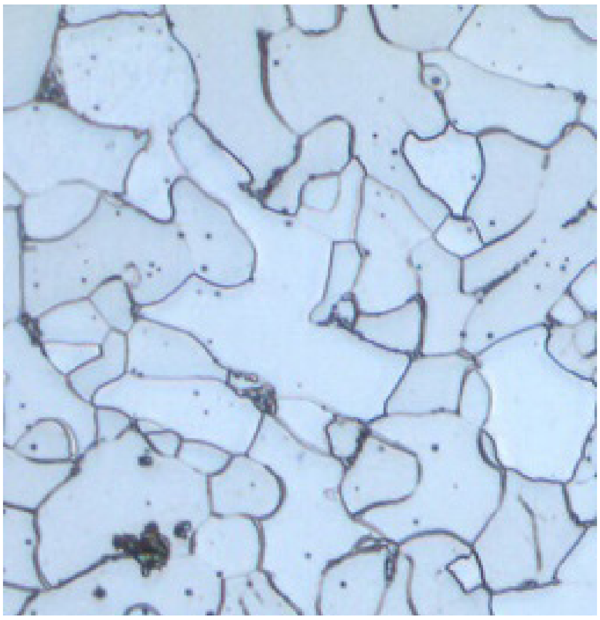


Fig. 1.8: Steel (*Ferritic steel) at* 50 µm

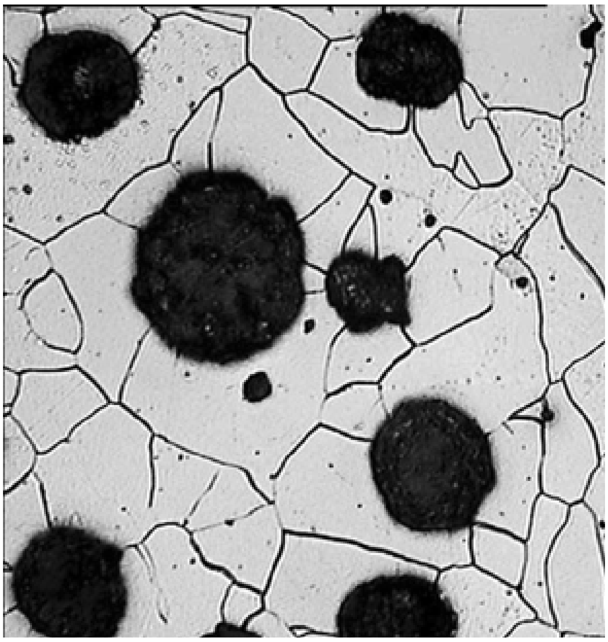


Fig. 1.9: *Cast iron (*Ferritic *cast iron) at* 50 µm

Fig. 1.10 Cast iron (*Pearlitic cast iron) at* 25 µm

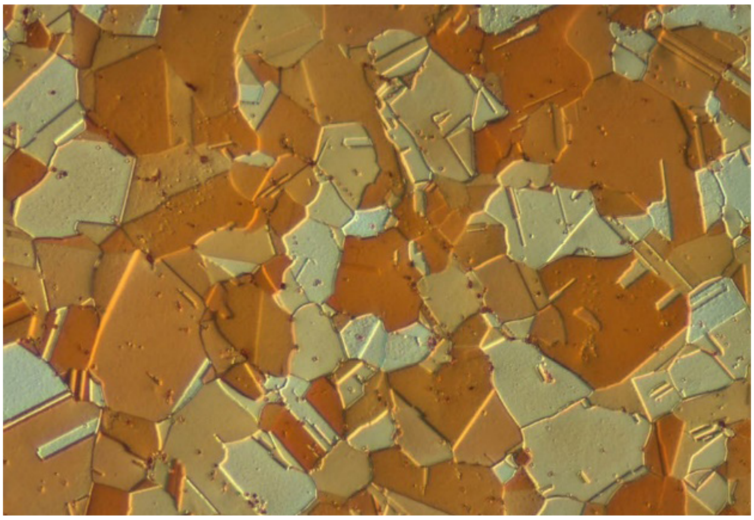


Fig. 1.11: Pure copper metal *at* 20 μm

Example of microscopic structure at a lower resolution

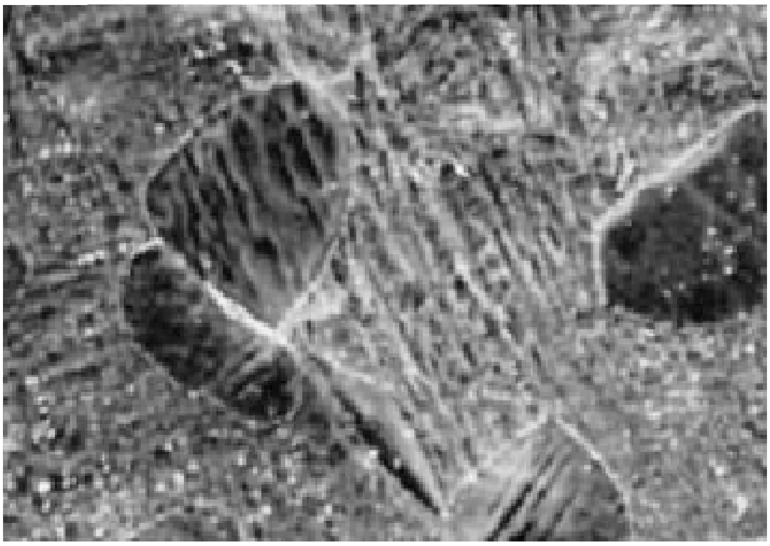


Fig. 1.12: Titanium alloy (Ti-6Al-4V) at 5 μm

Within these grains, the atoms are densely packed in a specific crystallographic orientation, forming regular patterns and boundaries known as grain boundaries where different grains meet.

The microscopic structure can be changed by the following methods:

a. **Heat Treatment:** Heat treatment involves subjecting the material to controlled heating and cooling processes to modify its microstructure.
b. **Mechanical Processing:** Mechanical processing techniques such as rolling, forging, extrusion, and drawing can change the microstructure of metals by causing plastic deformation.
c. **Alloying:** Alloying involves adding alloying elements to the base material to modify its microstructure.

d. **Phase Transformation:** Phase transformation occurs when a material undergoes a change in its crystal structure or phase composition due to changes in temperature, pressure, or chemical composition.

e. **Surface Treatment:** Surface treatments such as shot peening, nitriding, carburizing, and surface coatings can modify the microstructure of a material near its surface.

f. **Ion Implantation and Irradiation:** Ion implantation and irradiation techniques involve bombarding the material with energetic particles to introduce defects and modify both atomic structure and crystal structure. This method is usually used to change the material structure and properties for specific applications, such as semiconductor devices and nuclear materials.

Macroscopic Structure

The macroscopic structure of a metal is its grain structure at a scale visible to the naked eye or under a low-magnification hand lens (magnifying glass). The macroscopic structure of a metal refers to its overall physical appearance at a scale visible to the naked eye or under low-magnification microscopy. It includes features such as the size, shape, and arrangement of grains, as well as any visible defects or imperfections within the material.

The size, shape, and orientation of these grains can vary depending on factors such as:

a. The manufacturing process used for the material

b. Application of heat to the material and

c. Alloy composition of the material.

Fig. 1.13 below illustrates the macroscopic structure of a titanium alloy, while Fig. 1.14 shows the macroscopic and microscopic structure of a locally available material (bamboo).

Fig. 1.13: Macrostructure of Titanium alloy (Ti-6Al-4V) at a resolution of 1 mm

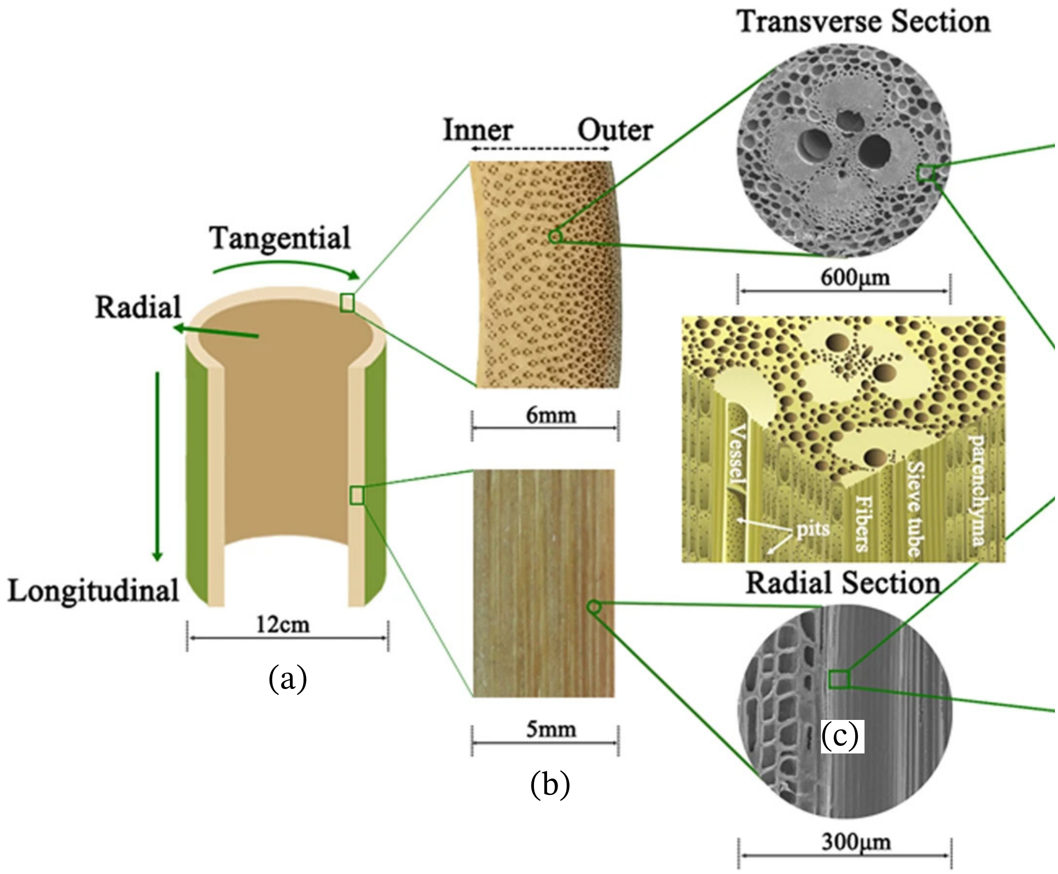


Fig. 1.14: Macroscopic and microscopic structure of bamboo: (a) Actual bamboo (b) Macroscopic structure at low resolution of 5 mm and 6 mm (c) Microscopic structure at a higher resolution of 300 and 600 μm

Properties of Material

The property of the material is the set of characteristics or attributes that describe its behaviour under certain conditions. These properties can be mechanical, chemical, physical, thermal, electrical, optical, or magnetic. For each property, there is a characteristic type of stimulus capable of provoking different responses. These properties can vary significantly depending on the specific metal and its composition, microstructure, processing history, and environmental conditions.

1. **Mechanical properties** relate deformation to an applied load or force; examples include elastic modulus (stiffness), strength, and toughness.
2. **Electrical properties**, such as electrical conductivity and dielectric constant, relate to an electric field.
3. **The thermal properties** of solids can be demonstrated by their heat capacity and thermal conductivity.
4. **Magnetic properties** demonstrate the response of a material to the application of a magnetic field.
5. **Optical properties** such as the index of refraction and reflectivity have stimuli such as electromagnetic or light radiation.

6. **Chemical properties** relate to the structural features and composition of the compounds that make up the material.
7. **Physical properties** relate to the colour, appearance, and shape of the material.

Processing of Engineering Materials

Materials are generally processed by either heat or mechanical force. This may cause changes in the microstructure of the material that will directly affect the properties of the material. The processing of engineering materials encompasses the methods and techniques used to transform raw materials into finished or semi-finished products to attain the desired material structure and properties. The choice of processing methods mainly depends on the following factors:

1. The types of material to be processed.
2. Anticipated material structure.
3. Desired properties.
4. Processing cost considerations.

Most of the processing methods rely on the application of one or a combination of the following conditions to the material:

1. laser beam
2. heat
3. mechanical force (pressure)

These conditions cause changes in the microstructure of the material, which affects its properties.

Some of the processing methods used in the manufacturing industry include the following:

1. **Melting:** Melting is a fundamental process in the production of metals. It involves converting solid metal materials into a molten state for further processing and shaping.
2. **Casting:** Casting involves pouring molten metal or other materials into a mould, where it solidifies to form the desired shape.
3. **Refining:** Refining is a process used in metallurgy to extract and purify metals from ores, which are naturally occurring mineral deposits containing valuable metal compounds.
4. **Mixing:** Mixing involves blending various polymer ingredients to create a homogeneous mixture with desired properties.
5. **Grinding:** Grinding is a mechanical process used in ceramics manufacturing to shape and finish ceramic materials into precise dimensions and surface qualities. It is an essential step in the production of ceramic components, as it allows for the removal of material and the attainment of the desired shape, size, and surface finish.

6. **Sintering:** Sintering is a process used to bond particles of a powdered material into a solid mass without melting the material completely. It is commonly used in powder metallurgy and ceramics manufacturing to produce parts with desired shapes and properties.
7. **Forming:** Forming processes include techniques such as forging, rolling, extrusion, and stamping, which deform a workpiece to obtain the desired shape. These methods are commonly used for metals and plastics to produce components with a specific range of dimensions and properties.
8. **Composite Manufacturing:** Composite materials are made by combining two or more distinct materials to create a new material with enhanced properties. Composite manufacturing techniques, including lay-up, filament winding, and resin transfer moulding, are used to produce lightweight, strong, and durable components for the aerospace, automotive, and construction industries.

The Relationship between the Structure, Properties, Processing and Performance

The structure of engineering materials governs the properties, processes, and performance of these materials. It is required of the scientists and engineers to also think of the impact the material will have on the environment. The consideration of these five dimensions of engineering materials is known as the "materials science octahedron." The relationship between structure, process, property, performance, and the environment is illustrated in **Fig. 1.15.** It is a useful guideline in the field of engineering materials. For instance, the best-performing engineering material cannot be sustained or patronised (accepted) by the users if it has a serious effect on the immediate environment of the end users. Similarly, if the processing technique of a material has negative implications for the environment, it cannot be accepted by society.

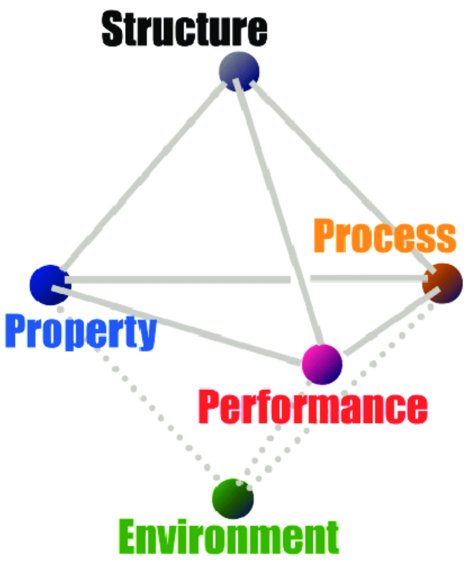


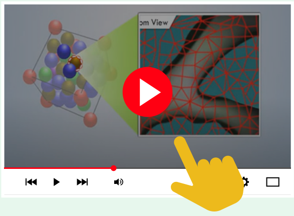
Fig. 1.15: The materials science octahedron

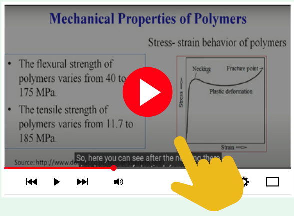
1. **Structure:** The structure of a material refers to its internal arrangement of atoms, molecules, grains, phases, and defects. This includes features such as grain size, grain boundaries, crystallographic orientation, phase composition, and the presence of defects like dislocations and vacancies. The structure influences the material's mechanical, thermal, electrical, magnetic, and optical properties.
2. **Properties:** Properties are the characteristics or attributes of a material that describe how it behaves under various conditions. These include mechanical properties such as strength, hardness, toughness, ductility, and elasticity, as well as thermal conductivity, electrical conductivity, corrosion resistance, and many others. The properties of a material are directly influenced by its structure.
3. **Processing:** Processing refers to the methods and techniques used to transform raw materials into finished engineering materials or semi-finished materials with desired properties. Processing methods such as casting, forming, machining, heat treatment, surface treatment, and joining can alter the structure of the material, thereby affecting its properties. The choice of processing method and parameters can significantly impact the final performance of the material and the environment.
4. **Performance:** Performance refers to how well a material performs in a specific application or service environment. It includes factors such as durability, reliability, efficiency, and functionality. The performance of a material depends on its properties, which are influenced by its structure and processing method. By understanding the relationships between structure, properties, and processing, as well as the environment, engineers can adapt materials to meet the performance requirements of a wide range of applications.
5. **Environment:** Environment refers to the effects of material processing, use, and disposal on the environment, including energy consumption, resource depletion, pollution, and greenhouse gas emissions. Understanding the environmental impact of new materials is crucial for promoting sustainable practices and mitigating the possible negative environmental effects.

The relationship between structure, properties, processing, performance, and environment is interconnected and dynamic. Changes in one aspect can affect others, thus requiring careful consideration and evaluation throughout the material development and manufacturing process. Materials scientists and engineers employ various techniques, such as microscopy, spectroscopy, mechanical testing, and models, to study and adjust these relationships, enabling the design of materials with custom-made properties and improved performance for specific applications that are environmentally friendly.

Activity 1.1

1. Watch the following videos on material structure and processing and complete the tasks that follow:





   a. Use sketches to show three structures (atomic, microscopic, and macroscopic) of a named material.

   b. Use a chart to explore the processing of one engineering material in the manufacturing industry. An example is given below.

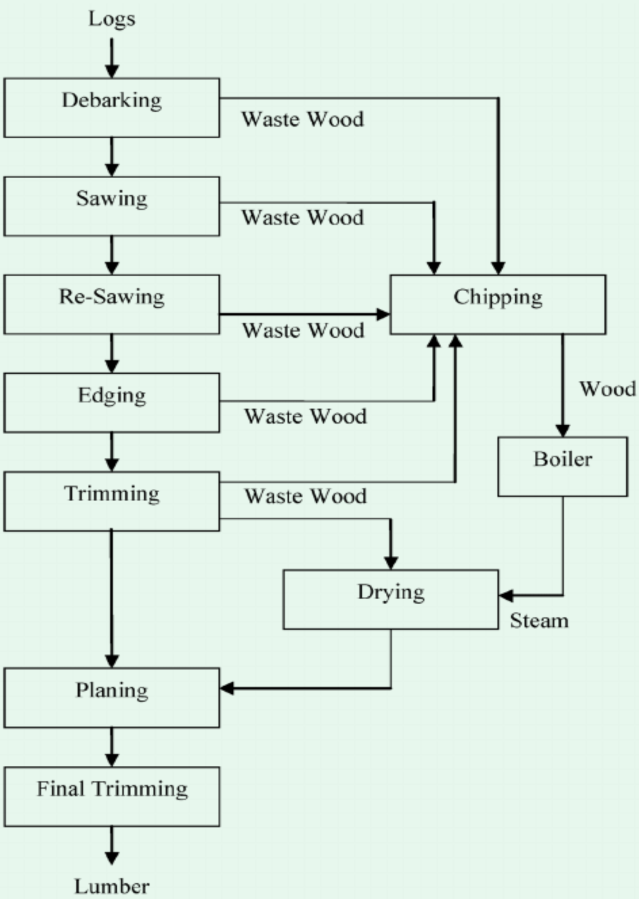


Fig. 1.16: Processing of Timber Logs into Lumber (wood)

2. Imagine you are exploring local products in your community. You come across several traditional crafts and products that involve processing materials to create useful items. Investigate two different methods used to process these items and compare their strength or durability levels.

Questions:

a. Identify one local product you came across while exploring your community.

b. State and describe two methods used in processing or manufacturing the product you have identified.

c. Compare the strength or durability levels of the two methods you have mentioned.

See an example below:

Product: Ceramic Cup

Methods:

i. **Hand-building:** Shaping clay by hand using coiling and sculpting techniques.

ii. **Throwing on a potter's wheel:** Shaping clay on a spinning wheel to create a symmetrical, cylindrical shape.

Comparison of Strength or Durability Levels:

i. Hand building typically results in lower strength due to potential weak points in the coils and joints.

ii. Throwing on a potter's wheel achieves higher strength because of the even distribution of clay and the compression of the material during the throwing process.

Activity 1.2: Group work

1. In small groups, research materials to explore the relationship between processing, structure, properties, and performance.
2. Prepare a PowerPoint presentation and present your findings to the class.

Activity 1.3

Create a worksheet to identify three (3) everyday products, the materials used in manufacturing them and the reasons for using these materials.

See the example below:

Worksheet to Identify Everyday Products, The Materials Used in Manufacturing Them and The Reasons for Using These Materials.

Everyday item: bicycle.

Materials used in this item: steel, aluminium, carbon.

Material 1: Steel

Properties of steel: strong and durable.

Reasons for using steel: It is ideal for making frames.

Material 2: Aluminium
Properties of aluminium: lightweight, corrosion-resistant.
Reasons for using aluminium: best for making components.
Material 3: Carbon
Properties of carbon: lightweight and stiff.
Reasons for using carbon: used for making frames and parts.

Now, create a similar worksheet for your answers. Note: Do not use the everyday item in the example above.

Activity 1.4

1. In groups of three, select three common materials from your homes or communities.

   Instruction: Always ensure that a teacher or parent supervises your activity. Wear hand gloves, safety boots and goggles. Work in a well-ventilated and organised area, handle materials carefully and report any unsafe conditions to your supervisor.
2. For each material, perform the following actions:
   a. bend with pliers
   b. Shear with scissors
   c. Twist with pliers and
   d. Crush with a hammer.
3. Discuss two primary uses of each selected material.
4. Tabulate your observations and the uses of each material using the headings shown in **Table 1.1** below.

Table 1.1

Name of material	Bending with pliers	Twisting with pliers	Shearing with scissors	Crushing with hammer	Major use of material (1)	Major use of material (2)
a.						
b..						
c.						
d.						
e.						
f.						
g.						
h.						
i.						

5. Present your findings orally to the class.

Activity 1.5

1. Choose one material from your community.
2. Carefully cut through the material to expose its internal surface.
3. Use a hand lens or magnifying glass to examine it closely.
4. Sketch what you observe on an A4 sheet.

Activity 1.6

This activity should be done under the supervision of your teacher or facilitator.

1. Choose one material from your community.
2. Carefully cut through the material to expose its internal surface.
3. Use a microscope to examine it closely.
4. Sketch what you observe on an A4 sheet.

Activity 1.7

1. Create mind maps illustrating all potential uses of a locally available material in your community.
2. Provide reasons why you think community members prefer this material.
3. Prepare a report and deliver a presentation to your peers in class.

Activity 1.8

Wear hand gloves and appropriate protective clothing before performing the following tasks:

1. Use pliers to bend and twist a damaged kitchen knife (Note: you can use a piece of iron rod if you don't have a damaged kitchen knife).
2. Next, place the same knife in a coal pot fire until it turns red-hot. Afterwards, use the pliers again to bend and twist the heated knife.
3. Record your observations and findings to discuss with the class.

Activity 1.9

After the tour to a local material manufacturing or processing site with your teacher, write a report on the processing of materials observed on the tour and how the processing enhanced the performance or use of that material or those materials.

Activity 1.10

1. In small groups, generate ideas on the relationship between material science and material engineering, considering the four components of material science and engineering (i.e. processing, structure, properties, and performance of materials). *Refer to Fig. 1.1*

Follow the guidelines below to generate ideas on the importance of mechanical of material

   a. What determines the structure of a material?
   b. What determines the property of a material?
   c. What determines the performance of a material?

2. You have been employed by MITCON Company Ltd. as a material scientist and engineer. Recently, your company won a contract to construct a new bridge over the Boin River at Assemkrom located in the Aowin Municipality of the Western North Region of Ghana. As the head of the Material Selection Department, explain briefly what factors will inform your choice of materials for the construction of the bridge.

Extended Reading

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3. Shackelford, J.F., 2016. Introduction to materials science for engineers (p. 687). Upper Saddle River: Pearson.
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CLASSIFICATION OF MATERIALS INTO METALS AND NON-METALS

Different materials are used for different purposes and applications. Understanding the differences among the various kinds of materials used for manufacturing will help you identify and determine which material is best suited for the work at hand. Materials in general are grouped under metals or non-metals. Due to technological advancement new materials such as nanomaterials, smart materials, and alloys have been developed to satisfy the current demand for materials.

Classification of Materials

Materials have been classified into metals and non-metals based on their physical, mechanical, and chemical properties.

Metals

Metals have high thermal and electrical conductivity and are strong yet deformable under applied mechanical loads. They are opaque to light, with their atoms bound together by metallic bonds and weaker intermolecular forces. Pure metals are not good enough for many applications, especially structural applications. They are, therefore, used in the form of alloys. Examples of metals include iron, aluminium, copper, gold, titanium, and steel.

Metals have numerous applications, such as nails and screws, automobile parts, utensils, machinery, and hammers. The table below shows examples of objects made from metal.

Table 1.2: Examples of objects made from metals

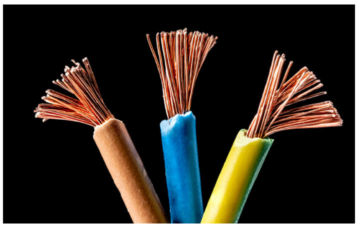
Image	Description
	Copper wires are used for electric cables due to their high electrical conductivity.
	Some frying pans are made of aluminium.

Image	Description
	Some rings are made of gold.
	Nails are made from metals such as steel.

Properties of Metals

Metals have different properties that make them suitable for engineering applications. These properties have made metals technologically and commercially important as engineering materials. They include:

1. **High stiffness and strength:** Metals can be alloyed for high rigidity, strength, and hardness; thus, they are used to provide the structural framework for most engineered products.
2. **Toughness:** Metals can absorb energy better than other classes of materials.
3. **Good electrical conductivity**: Metals are conductors because of their metallic bonding, which permits the free movement of electrons as charge carriers.
4. **Good thermal conductivity:** Metallic bonding also explains why metals generally conduct heat better than ceramics or polymers.
5. **Malleability:** Metals can be beaten into different shapes.
6. **Ductility:** Metals can be stretched into wires.

Alloys

Metals can also be artificially created by combining two or more elements, with at least one being a metal element to form an *alloy.* Creating alloys improves the properties of natural metals, making them useful in many applications. Examples of alloys include stainless steel, bronze, brass, duralumin, carbon steel, and steel. Table 1.3 shows some examples of objects made from alloys.

Table 1.3: Examples of objects made from alloy

Image	Description
	Taps and sinks are made of stainless steel.
	Trumpet is made of brass.
	The image shows a medal made from bronze.

Ferrous and Non-Ferrous Metals

Metals containing iron in their composition are called *ferrous metals* and can be attracted by magnets. Some examples of ferrous metals are iron, stainless steel, carbon steel, cast iron, wrought iron, and steel (which includes mild steel, medium carbon steel, high carbon steel, alloy steel, stainless steel, and high-speed steel).

Metals that do not contain iron are called *non-ferrous metals*, and they are not attracted by magnets. Examples of non-ferrous metals include aluminium, aluminium alloys, copper, copper alloys, magnesium, magnesium alloys, nickel, nickel alloys, titanium, titanium alloys, zinc, and zinc alloys.

Non-Metals

Non-metals are materials that have no metal element in their composition. According to the definition, any material that is not a metal can be classified as a non-metal, and these include ceramics, polymers, composite materials, semiconductors, and advanced materials. Some properties exhibited by non-metals are:

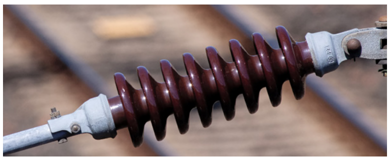
1. They are good insulators of electric current due to their poor electric conductivity.
2. They have low melting points.
3. They are poor conductors of heat.
4. They have poor thermal conductivity.
5. They are neither ductile nor malleable.
6. They generally have a dull appearance.

Ceramics

Ceramics are non-metallic, inorganic materials usually made of oxides, nitrides, or silicates of metals. Ceramics are typically partly crystalline and partly amorphous. Atoms or ions in ceramic materials mostly behave like positive and negative ions and are bound by very strong Coulomb forces between them. They are characterised by very high strength under compression and low ductility; they are usually insulators to heat and electricity. Common ceramic materials include glass, pottery, tiles, bricks, and cookware.

Ceramics are made by shaping and firing a non-metal, such as clay to form earthenware or silica to form glass. **Table 1.4** shows some examples of objects made of ceramic materials.

Table 1.4: Some examples of objects made of ceramic materials.

Image	Description
	Tableware is made of ceramic material.
	Glass cups
	These are examples of ceramic insulators used in electric power lines.

Polymers

Long chains of repeating molecules known as monomers make up polymers. Polymers include plastics and rubber materials. Many polymers are organic compounds that are chemically based on carbon, hydrogen, and other non-metallic elements (i.e., O, N, and Si). Due to the type of bonding, polymers are typically electrical and thermal insulators. However, conducting polymers can be obtained by doping, and polymer-matrix composites can be obtained by the use of conducting fillers. They decompose at moderate temperatures of about 100 to 400 °C and are lightweight. Some common polymers are polyethylene, polyester, Polyvinyl Chloride (PVC), polypropylene, polycarbonates, nylon, epoxy, vinyl ester, polyurethane, phenolic resin, and silicon rubber. Some examples of objects made of polymers are shown in **Table 1.5**.

Table 1.5: Examples of objects made from polymers

Image	Description
	These are pipes used in water plumbing works are made of PVC.
	Examples of polyethylene packages.
	Nylon ropes are used for climbing.
	Close-up view of a silicone gun on the floor with silicone sealant leaking out of it.

Composite Materials

Composite materials are made up of two (or more) individual materials, such as metals, ceramics, and polymers. The design goal of a composite material is to achieve a combination of properties that are not displayed by any single material, thereby combining the best characteristics of each component material. Some naturally occurring composites are wood and bones. However, most composites used in manufacturing are artificially made, such as fibreglass, carbon fibre reinforced polymer (CFRP), Kevlar, and reinforced concrete.

CFRP is used in the manufacturing of parts of high-tech sporting equipment and parts of an aeroplane due to its lightweight and high strength of materials. **Table 1.6** shows examples of objects made from composite materials.

Table 1.6: Examples of objects made from composite material.

Image	Description
	Propeller shafts of sports vehicles are made with a CFRP.
	This image shows a bulletproof vest made from Kevlar material.
	This image shows a concrete poured on a steel reinforcement bar to form strong floor slabs called reinforced concrete floor slabs.
	The image shows a Plaster of Paris (POP) which is used in the medical field.

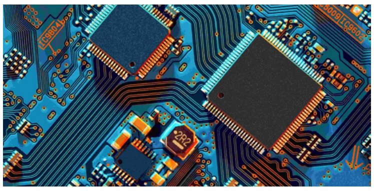
Advanced Materials

Advanced materials are materials used in high-tech applications such as lasers, batteries, magnetic information storage, liquid crystal displays (LCDs), and fibre optics. They are designed to have superior properties and performance compared to conventional materials. These composites are mostly developed through innovative research and technological advancements and often find applications in cutting-edge industries and technologies. Advanced materials play a crucial role in enhancing the capabilities of various engineering disciplines. Some examples of advanced materials include semiconductors, biomaterials, smart materials, and nanomaterials.

Semiconductors

Semiconductors have electrical properties that are intermediate between electrical conductors and insulators. They are an essential component of modern electronics and are used in everything from computers and smartphones to cars and medical equipment, as can be seen in **Table 1.7.** Examples of semiconductor materials include silicon, germanium and gallium arsenide.

Table 1.7: Example of semiconductor application.

Image	Description
	This is an image of an electronic circuit board made with semiconductors.

Biomaterials

Biomaterials are non-living materials implanted into the human body to function reliably, safely, and effectively while interacting with living tissue. These materials must be biocompatible with body tissues and should not produce toxic substances. Important material factors include the ability to support forces, low friction, wear resistance, density, cost, and reproducibility. Examples of biomaterial applications include joint (e.g., hip, knee) and heart valve replacements, vascular grafts, fracture-fixation devices, dental restorations, contact lenses, and the generation of new organ tissues. Examples are seen below in **Table 1.8**.

Table 1.8: Examples of biomaterial applications.

Image	Description
	An image of a dental implant made of biomaterials.

Image	Description
	Close-up image of a woman inserting a contact lens in her eye.

Smart Materials

Smart materials are a group of new and state-of-the-art materials that are able to sense changes in their environment and then respond to these changes in predetermined manners—qualities that are also found in living organisms. Examples of objects that use smart materials include thermostats, smart sensors, shape memory alloys, and smart fabrics, as shown in Table 1.9. Some examples of smart materials are:

1. Shape-memory alloys are metals that, after having been deformed, revert to their original shape when the temperature is changed.
2. Piezoelectric ceramics expand and contract in response to an applied electric field or voltage, and they also generate an electric field when their dimensions are altered.
3. Magnetostrictive materials expand and contract in response to an applied magnetic field and they also generate a magnetic field, when their dimensions are altered.
4. Electrorheological fluids are liquids that experience dramatic changes in viscosity upon the application of electric fields.
5. Magnetorheological fluids are liquids that experience dramatic changes in viscosity upon the application of magnetic fields.

Table 1.9: Examples of smart material applications.

Image	Description
	Assemblies made of shape memory alloys are used as thermal actuators in the automotive industry, as well as in various fields of measurement and control technology, and appliance technology.
	This is an image of a pile of piezoelectric diaphragms. Parts for piezo tweeter assembly. Niche and specialized speaker industry.
	This is an image of magnetostrictive linear position sensors with a display.

Nanomaterial

Nanomaterials are materials with a single unit sized between 1 and 100 nanometres (10-9). They are designed and built from their atomic-level constituents, one atom or molecule at a time, with the use of scanning probe microscopes. Some examples of nanomaterials include carbon nanotubes, graphene, and quantum dots. **Table 1.10** shows examples of objects made with nanomaterials.

Table 1.10: Examples of nanomaterial applications.

Image	Description
	Nanomaterials are used in paints and coatings, for example, to improve durability and to provide new functionalities, i.e., water/dirt repellent 'easy to clean', antimicrobial resistance, or scratch resistance.
	Nanoparticles are used to make glass photocatalytic, which makes it energised when ultraviolet rays fall on it and start loosening the dirt particles on the glass.

Activity 1.11

1. In pairs, collect objects in the classroom and group them into metals and non-metals. Create a table similar to the one below to record and indicate the different kinds of material.

SN	Object	Material	Metal or Non-metal
a.	Pen	Plastic	Non-metal
b.			
c.			
d.			
e.			
f.			

2. Differentiate between ferrous and non-ferrous metals using a magnet. Below are some steps to guide you:
   a. Collect or gather different metal samples like iron, copper, aluminium, etc., from your surroundings or community. Find as many different samples as you can.
   b. Hold the magnet near each metal sample.
   c. Note whether the metal is attracted to the magnet or not.

d. Place metals attracted to the magnet into the ferrous metals group.
e. Place metals not attracted to the magnet into the non-ferrous metals group.

3. In pairs, research and complete the chart below to compare the physical properties of metals and non-metals.

Comparison chart to show the physical properties of metals and non-metals

Physical Property	Metals	Non-metals
State at Room Temperature		
Lustre		
Conductivity		
Malleability		
Ductility		
Density		
Melting and Boiling Points		
Hardness		
Sonority		
Appearance		

Below are some guidelines to help you perform the activity above.

a. **Metals**: Metals are typically found on the left side and in the centre of the periodic table. They form positive ions by losing electrons, and they tend to form metallic bonds
b. **Non-metals**: Non-metals are found on the right side of the periodic table (except for hydrogen). They tend to gain electrons to form negative ions and often form covalent bonds.
c. Use this link to watch a video on the properties of metals and non-metals and create a chart to compare these properties.

4. Work in groups to design a desk that meets the needs of the students and teachers in your school. To design the desk, you are required to select metals or non-metals based on their properties, cost, availability, functionality, and environmental impact.

This group project requires research and practical work. Follow the guidelines below to assist you.

a. Meet with your team to discuss the desk design, including size, shape, height, storage options, and comfort.

b. Research different materials (i.e. metals and non-metals) for constructing the desk. Consider their strength, durability, weight, and flexibility.

c. Evaluate the cost, availability, and sustainability of each material.

d. Choose materials that best fit the desk's needs, considering fabrication ease, maintenance, and compatibility with other components.

e. Choose materials that best fit the project requirements based on your research.

f. Balance performance and cost, and consider the environmental impact of your choices.

g. Sketch the desk design with a pencil and ruler on an A4 or A3 sheet, including dimensions, features, and how it will be assembled.

h. Ensure the design is safe and comfortable for students and teachers.

i. Document your research and explain why you chose each material.

j. Include information on the properties, cost, availability, functionality, and environmental impact of each material.

k. Justify your material choices based on their suitability for the desk.

l. Present your design and report to the class for review.

Extended Reading

1. Callister, W. D., & Rethwisch, D. G., (2020). *Materials Science and Engineering: An Introduction*, 9th Edition, John Wiley & Sons. Chapters 13, 14, 15 and 16
2. Tiwari, A., Murugan, N. A., & Ahuja, R. (2016). *Advanced Engineering Materials and Modeling*. John Wiley & Sons.
3. Donahue, C. J., (2019). *Reimagining the Materials Tetrahedron,* Journal of Chemical Education, 96, 12, 2682–2688.
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CLASSIFICATION OF MATERIALS ACCORDING TO THEIR INDUSTRIAL APPLICATIONS

The application of materials in various industries is hinged on their characteristics, properties and suitability for a specific task. Every industry has its own unique requirements for which materials are selected or grouped. The main factors for selecting the material for industrial applications are numerous and include thermal, chemical, or mechanical resistance, ease of manufacturing, and durability.

Classification of Materials According to their Industrial Applications

Materials are classified into various categories based on their industrial applications.

1. **Clothing industry:** The clothing industry utilises a diverse range of materials with unique properties and characteristics that contribute to the design, functionality, and durability of the garment. It is one of the production industries that caters to the evolving needs and preferences of customers. Materials commonly used in the clothing industry have been grouped as follows:
    a. **Natural fibres**: These are raw materials obtained from plants and animals, e.g., cotton, wool, silk, leather, and linen. Natural fibres are extensively used in the clothing industry because they are soft, comfortable, breathable, and light in weight.
    b. **Synthetic fibres**: These are manufactured or processed materials. Examples include polyester, nylon, and acrylic. Synthetic fibres are noted for their durability, wrinkle resistance, and ease of maintenance.

Both natural and synthetic fibres can be blended to obtain unique properties like cotton and polyester (cotton-polyester) for comfortability and longevity. **Table 1.11** shows clothing material applications and properties.

However, certain clothing materials do not fit into these categories. Such materials include pigments, dyes, fillers, binders, and recycled materials.

Table 1.11: Shows a list of natural and synthetic fibre materials and their applications in the clothing industry.

Material Category	Material	Properties	Application/ Products
Natural fibres	Cotton	Soft, breathable, and absorbent.	T-shirts, dresses, underwear,
	Wool	Warm, resilient, and elastic.	Sweaters, hats and other winter clothing.
	Silk	Smooth, soft, and natural sheen.	Dresses and blouses.
	Linen	Lightweight, breathable, and absorbent.	Summer (hot climate or weather) clothing.
Synthetic (Processed) fibres	Polyester	Durable, wrinkle resistant, and has shape retainability.	Sportswear, outdoor clothing and everyday wear.
	Nylon	High strength, elastic, and resistant to abrasion.	Sportswear, swimwear and hosiery.
	Rayon	Soft, comfortable, and highly absorbent.	Dresses, blouses and linings.
	Acrylic	Lightweight, warm, and soft.	Sweaters and fleece clothing.

2. **Building industry**: The building industry uses different kinds of materials such as wood, sand, laterite, cement, steel, plastic, stone, glass, bamboo, carbon fibre, raffia, and straw. These materials can be grouped under natural and man-made building materials. Natural building materials are materials that have undergone little to no processing, while manufactured building materials are man-made or processed materials. Natural building materials are environmentally friendly and cost-effective, but they are not mostly durable. Nevertheless, there are different types of materials that are considered eco-friendly. These materials have a low environmental impact. **Table 1.12** presents the application of natural and manufactured building materials.

Table 1.12: Application of natural and manufactured building materials

Material Category	Material	Properties	Application/ Products
Natural building materials	Wood	High-strength, durable, absorbent	Structural applications, flooring, and furniture
	Stone	Durable, aesthetically pleasing, and high-strength	Exterior and interior walls, concrete reinforcement, core filling.
	Sand	Granular texture, Porous, permeable, and abrasive.	Moulding bocks, bricks, water-filtration concrete, and mortar mix.
	Laterite	Porous, good thermal conductivity, cheap	Bricks, landscaping, road construction, wattle, and *atakpamé* building.
	Clay	Durable, good thermal properties	Bricks, tiles, ceramics, oven silos.
Manufactured (processed) building materials	Cement	High binding ability, ability to harden	Concrete and mortar mix, creating stucco on walls and ceilings.
	Steel	High strength, durable	Wide-range structural applications.
	Concrete	High strength, durable	Wide structural applications.
	Bricks	Durable, good thermal properties	Walls, paved floors, building chimneys, furnaces, and ovens
	Tiles	Durable, aesthetic appeal	Flooring and walls.
	Finishes	Good adhesion, good resistance to water, easy to apply	Surface protection and waterproofing, enhancement of appearance, sealing of pores.
Eco-friendly materials	Bamboo	High-strength, lightweight, renewable	Structural applications
	Raffia	High strength, lightweight, renewable, breathable	Production of textiles, hats, mats, bags, and baskets
	Recycled materials	Renewable, low energy consumption	Recycled steel, glass, and plastic

3. **Automotive industry**: The automobile industry makes use of diverse materials to meet the requirements of vehicle design, performance, safety, and sustainability. The main materials used for making cars, parts, and components, along with future trends, are steel, aluminium, magnesium, copper, plastics, carbon fibre, and specialised materials for electric vehicles (EVs). Advancements in material science and engineering have led to the development of innovative materials that offer enhanced properties, such as lightweightness, improved fuel efficiency, and increased safety. **Table 1.13** outlines the application of materials used in the automobile industry.

Table 1.13: Materials used in automobile industries.

Material Category	Material	Properties	Application/ Products
Metals	Steel	High strength, durability, heat resistance, versatility	Car bodies, engines, chassis, and propeller shaft
	Magnesium	Lightweight, low melting point, corrosion resistance, High stiffness,	Steering wheels, engine blocks, gearbox, driver's airbag housings, and seat frames. etc.
	Aluminium and its alloy	Lightweight, malleable, ductile, good conductor of heat	Engines, wheels, and body panels
Plastics and composites.	Polypropylene (PP)	Chemical resistance, highly mouldable, suitable for parts with complex and intricate designs	Bumpers, gas cans, and engine covers.
	Polyurethane (PUR)	High-strength, resilient, and easy to mould	Seats, headrests, and bumpers.
	Carbon fibre	High in strength, strong and stiff, light in weight	Car body panels, suspension parts of cars, aircraft and spacecraft parts, racing car bodies, golf club shafts, automobile springs, sailboat masts,
	Polyvinyl Chloride (PVC)	Water resistance, chemical resistance, impact resistance, durability	Cable insulation and instrument panels
Rubber	Rubber	Flexible, durable, ability to absorb shock	Tyres, seals, and hoses

Material Category	Material	Properties	Application/ Products
Lead	Lead	Heavy in weight, poor conductor of electricity, malleable ductile	Wheels, battery accumulators
Glass	Glass	Transparent, high-strength, and resistant to ambient weather conditions	Windows and windscreens.
Specialised Materials for Electric Vehicles (EVs)	Specialised Materials for Electric Vehicles (EVs)	Good electrical properties	Lithium-ion batteries

4. **Food processing industry**: Materials used in the food processing industry are diverse and are carefully chosen for their compatibility with food and the regulatory standards of the industry. Common materials used in the food processing industry include stainless steel for equipment, food-grade plastics for packaging, glass for containers, and various food-safe coatings and additives. Raw materials such as fish, nuts, fruits, vegetables, and cereals are very essential in the food processing industry. **Table 1.14** describes the application of materials used in the food processing industry.

Table 1.14: Application of materials used in processing industries.

Material Category	Material	Properties	Application/ Products
Raw Agricultural Commodities (Foods)	Raw agricultural commodities (fruits, vegetables, grains, dairy products, and meats)	Nutritional content, flavour, soft	Cooking, multivitamins, flavours
Processed Foods	Flour (dough flour, pastry flour)	Ability to form structure when mixed with water	Cooking, bread, cakes, and cookies
	Sugar (granulated, icing)	Sweetener, preservative	Cooking, cakes, and jams
	Oils and fats (plants and animal sources)	Texture enhancer, good thermal properties	Cooking, baking and texture enhancer.

Material Category	Material	Properties	Application/ Products
Additives	Preservatives (salt, vinegar, honey, lemon juice, rosemary, ascorbic acid, sodium nitrite)	Food shelf-life extension by inhibiting the growth of bacteria, yeasts, and moulds	Can food products, cooking, and preserving foods.
	Colours (such as beet juice, turmeric, paprika, saffron, matcha green, food sprays, edible gold and silver dust)	Makes food and drinks more visually appealing, neutralises food flavour	Drinks, food, and pastries such as cakes. decorations, cookies and biscuits.
	Flavourings (ginger, chilli, garlic powder, lemon zest, vanilla extract, cinnamon, etc.)	Enhances the taste and food flavour	Baking, cooking, beverages, snack foods, and confectioneries.
	Emulsifiers (mustard, honey, pectin)	Good food binding, enhances food mixing and increases shelf life.	Drinks, evaporated milk, ice cream, yoghurts, chocolates, and margarine.
Packaging Materials	Packaging materials (plastics such as PET, HDPE, PVC, PS, PP, LDPE, metals, glass, and paper)	Shelf-life extension and quality improvement ability	Take away plates, bowls, carbonated drinks (minerals), and fruit juice bottles.
Materials for Utensils, Equipment, and Machinery	Stainless Steel	High-strength, durable, and corrosion-resistance	Cutlery, cookware, various types of food processing equipment and self-service machines such as dispensers, vending machines, and ticket machines.
	Plastics (PC, PP, PA, PE, PES, UHMWPE, PVDF, Acrylic)	Lightweight, easy cleaning, resistance to breaking	Utensils such as spoons, spatulas, whisks, containers, and parts of food processing machinery. such as blenders, mixers, grinders, conveyor belts, and gears.

Material Category	Material	Properties	Application/ Products
Materials for Utensils, Equipment, and Machinery	Ceramics	Heat-resistant, easy cleaning, antimicrobial erosion, high mechanical strength, wear resistance	Cookware and bakeware such as kneading rollers, valve needles, grinding elements, and dosing sliders.
	Silicon	Heat-resistant, non-stick surface, flexible	Baking mats, utensils and seals for food processing machinery, food storage containers and bags, and non-stick coatings for cookware and bakeware.

5. **Electronic industry**: Materials used in the electronics industry have unique properties that make them suitable for a range of devices that drive our contemporary society. This diverse range of materials includes semiconductors, metals, ceramics, and polymers, each of which plays a distinct role in electronic device production and assembly. **Table 1.15** shows the applications of materials used in electronic industries.

Table 1.15: Application of materials used in electronic industries.

Material Category	Material	Properties	Application/ Products
Semiconductors	Silicon	Semi-metal properties	Microchips, semiconductor devices, sensors, microcontrollers, etc.
	Germanium		
	Gallium Arsenide (GaAs)		
Metals	Copper	Good electrical conductivity, ductile	Printed Circuit Boards (PCBs), Wiring and Cables, Heatsinks and Heat Exchangers, Busbars, and Power Distribution Systems.

Material Category	Material	Properties	Application/ Products
Metals	Nickel	High strength, good electrical and thermal conductivity, ductile, malleable, low melting point,	Thin-film resistors, battery electrodes, capacitors, transducers, and sensors.
	Chromium	Good electrical and thermal conductivity, ductile, malleable, low melting point,	Electroplating and decorative finishes.
	Aluminium	Good electrical conductivity and malleability	Printed circuit boards (PCBs), capacitors, heat sinks, and LED lights.
	Lead	Good electrical conductivity and malleability	Lead-based solder, capacitors, resistors, shielding, and radiation protection.
	Silver	Good electrical and thermal conductivity, malleability, and ductile	Photovoltaic cells, switches and relays, contacts, and connectors.
	Tin	Good electrical and thermal conductivity Ductile, malleable, low melting point,	Tin-based solder and dead frames
Plastics and Other Petroleum-Based Materials	Polystyrene (PST), Polyethylene Terephthalate (PET), and Polyvinylchloride (PVC)	Flexible, durable, and good electrical insulation	Capacitors and thermistors

6. **Medical and healthcare industry**: Materials in the medical and healthcare industry are biological materials (biomaterials). These have been grouped into natural and synthetic biomaterials. Proteins and polysaccharides are nature's form of polymers and are used in medical devices. The use of biomaterials increased rapidly, particularly after the advent of aseptic surgical techniques. The first metal device to fix bone fractures was stainless steel – a total hip replacement prosthesis was implanted. Later, polymers were introduced for corneal replacements and as

blood vessel replacements. A material suitable for all biomaterial applications and new applications is continually being developed as medicine advances. The selection depends on several factors, including the mechanical loading requirements, the chemical and structural properties of the material itself, and the biological requirements. Today, biomaterials are used throughout the body. **Table 1.16** shows biomaterials and their applications or uses in medical industries.

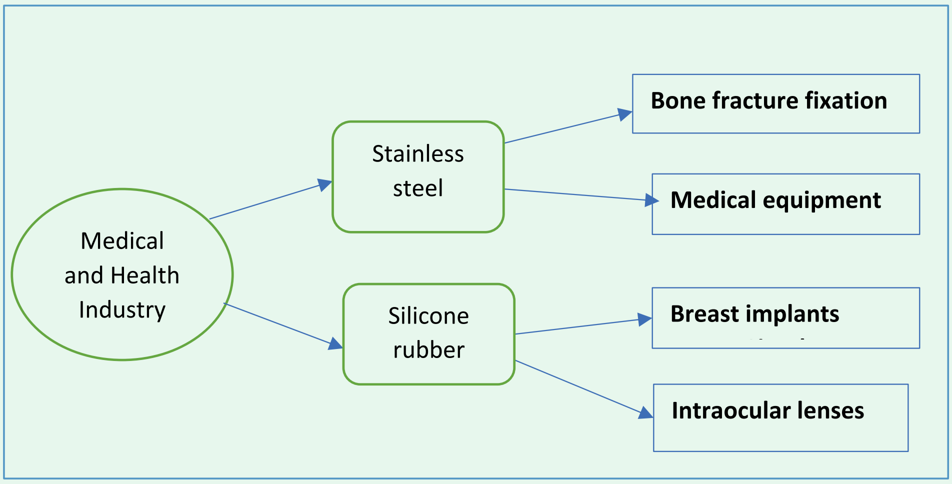
Table 1.16: Application of biomaterials used in the medical and healthcare industries.

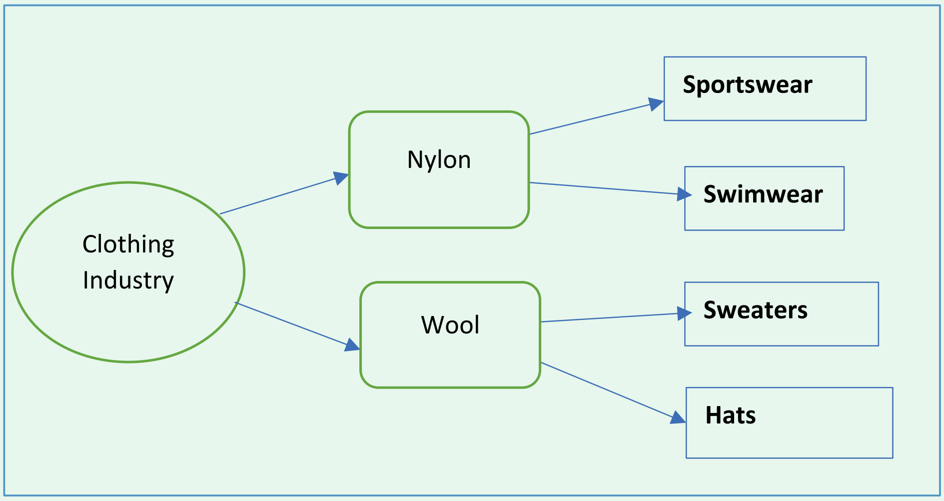
Material Category	Material	Application/ Products
Metal	Stainless steel	Joint replacements, bone fracture fixation, heart valves, electrodes, medical equipment, and devices.
	Cobalt-chrome alloys	Joint replacements and bone fracture fixation.
	Gold	Dental fillings and crowns, electrodes.
	Titanium and titanium alloys	Joint replacements, dental bridges, dental implants, and coronary stents.
Polymers	Nylon	Surgical sutures, gastrointestinal segments, and tracheal tubes.
	Hydrogel	Contact lenses, intraocular lenses, diapers, wound dressings, and sanitary products.
	Silicone rubber	Finger joints, artificial skin, breast implants, intraocular lenses, and catheters.
	Polyester	Resorbable sutures, fracture fixation, cell scaffolds, skin wound coverings, and drug delivery devices.
	Polyethylene (PE)	Hip and knee implants, artificial tendons and ligaments, synthetic vascular grafts, dentures, and facial implants.
	Polymethylmethacrylate (PMMA)	Bone cement, intraocular lenses.
	Polyvinylchloride (PVC)	Tubing, facial prostheses.

Material Category	Material	Application/ Products
Ceramics	Aluminium oxides	Hip implants, dental implants, and cochlear replacement.
	Carbon	Heart valve coatings, and orthopaedic implants.
	Glass	Bone graft substitutes, and fillers for dental materials.
	Calcium phosphate	Bone graft substitutes, surface coatings on total joint replacements, and cell scaffolds.
Pharmaceutical raw materials	Active pharmaceutical ingredients (APIs)	Drugs used for therapeutic effects.
	Excipients	Inactive substances that serve as vehicles for APIs.
Natural Materials	Collagen and gelatine.	Cosmetic surgery, wound dressings, tissue engineering, and cell scaffolds.
	Cellulose	Drug delivery.
	Chitin	Wound dressings, cell scaffolds, and drug delivery.
	Hyaluronic acid	Postoperative adhesion prevention, ophthalmic and orthopaedic lubricant, drug delivery, and cell scaffold.
	Alginate	Drug delivery and cell encapsulation.
	Ceramics or demineralised ceramics	Bone graft substitute.

Activity 1.12

1. Match materials based on industrial applications using mappings and charts. Follow the examples given below.





a. Now, create six mind maps of materials and at least two industrial applications used in the following industries:

i. Clothing industry
ii. Building industry
iii. Food industry
iv. Automobiles, industry
v. Electronics industry
vi. Medical and health industry

Activity 1.13 - Group work

1. (a) Generate ideas and discuss why steel is widely used in the automobile industry, copper in the electrical and electronic industry, and polyethylene (PE) in the medical and health industry. Use the following prompts to guide you in generating your ideas:

   i. What are the basic properties of steel, copper, and polyethylene that make them suitable for their respective industries?

   ii. Are there other materials used in the automobile, electrical and electronic, and medical industries?

   iii. Why are specific material properties necessary for these industries?

   iv. What properties of steel, copper, and polyethylene are most relevant to their respective industries? For example, the strength of steel is crucial in the automobile industry due to its ability to withstand shocks and impacts.

   v. Are there alternative materials that could be used in these industries?

   vi. How does understanding material properties help manufacturers make informed decisions?

   (b) Now, compare and contrast the characteristics that make a material suitable for use in the automobile industry and the medical industry.

   To do this, follow the guidelines below:

   i. Use the prompts in 1(a) to organise your ideas and thoughts.

   ii. Create a simple chart or table to compare and contrast the materials and their properties.

   iii. Summarise your findings in a report.

   iv. Present or share your findings with the class.

   v. In your presentation, explain why certain materials are chosen for specific uses.

Extended Reading

1. Callister, W. D., & Rethwisch, D. G., (2020). *Materials Science and Engineering: An Introduction*, 9th Edition, John Wiley & Sons. Chapters 13 and 15.
2. Tiwari, A., Murugan, N. A., & Ahuja, R. (2016). *Advanced Engineering Materials and Modeling*. John Wiley & Sons.
3. Donahue, C. J., (2019). Reimagining the materials tetrahedron, Journal of Chemical Education, 96, 12, 2682–2688.
4. Groover, M.P. (2012) Fundamentals of Modern Manufacturing. Wiley, Hoboken, NJ. Chapter 6 – 9

Review Questions

1. Your school has been nominated by an NGO as one of the derived schools in the region that is in serious need of classrooms and a constant electrical power supply. The NGO intends to provide for the needs of your school using sustainable solar panels and building materials such as bamboo and burnt bricks. As a materials science and engineering learner, explain why you agree or disagree with the proposal of the NGO to your class members who are not happy about the choice of materials for this project.
2. As the leader of a research team, explain to the class your role as a materials scientist or materials engineer in relation to the new materials your research team is currently developing.
3. List five (5) materials that can be found in the community and group them into raw and processed materials.
4. As a material scientist, explain how material evolution has imparted technological advancement in your country.
5. You have been invited to a television show for a discussion on the topic, 'The Link between Material Science and Materials Engineering'. As the first speaker on the panel, make a presentation on the topic.
6. How has technological advancement influenced the processing of local materials in your region or in Ghana?
7. Raffia and bamboo are very common materials in Ghana. State three properties of each to justify why they are normally used for roofing houses, and making chairs, tables, and buildings. Tabulate your answers in the table below.

Material	Justification/Properties
Raffia	
Bamboo	

8. Briefly describe how two (2) of the following engineering materials from your locality are processed into finished products.
   a. Wood
   b. Clay
   c. Aluminium sheet
9. Does the processing of the materials in question 8 have any effect on the environment? Discuss.

10. A bridge is to be constructed over a river that has some amount of salt in it. Discuss the material properties that are necessary to ensure the durability of the bridge.

11. A wooden bridge across a river leading to Esaase Bontefufuo Senior High School collapsed one busy afternoon. How did the structure, processing, and properties of the wood contribute to the collapse of the bridge? What alternative material can be used in the reconstruction of the bridge to prevent its failure? Consider the structure, properties, and processing of the alternative material in your analysis.

12. How does knowledge of the structure, processing, properties, and performance of materials, as well as their environmental implications, help the purchase and acquisition of products for everyday use in your community?

13. You are required to propose a material to be used in manufacturing a product that will work in high-temperature environments. Describe the desired properties the material should have to ensure its effective use in a high-temperature environment.

14. What properties should a material to be used along the coast possess, and why?

15. Which of the following would be the best material to use for transmitting current in the wiring of a house? Explain your answer.

    a. Rubber
    b. Copper
    c. Kevlar
    d. Silicon

16. What material will you select for making a bicycle frame for a bicycle racer? Explain your choice based on two properties of the material selected.

17. Describe what will happen if a metal and a plastic water bottle are exposed to a flame of fire.

18. You are required to recommend a material that prevents the flow of electricity and can be easily moulded into a glove for electricians. Would you recommend a metal or a non-metal? Explain your answer, naming some of the materials you will recommend.

19. A lightweight and corrosion-resistant material is needed for an aircraft component; suggest an appropriate material that can be used to manufacture this component. Explain your choice, considering the properties of the material.

20. Ekcoman Catering Services is a Ghanaian enterprise that deals with the preparation of local and continental dishes. Your mother happens to work as a cook in that enterprise, and she is not happy with the fact that the proprietor of the enterprise always spends so much money to buy expensive stainless steel utensils and cutlery while there are less expensive utensils and cutlery. As a manufacturing student, how would you help your mother understand why the proprietor always chooses stainless steel utensils and cutlery over other types?

21. Despite education on the potential harmful effects of plastics on the environment, many food vendors and market traders continue to use plastic products for packaging food. Write a short essay for discussion with your peers, highlighting the reasons why you think food vendors and market traders still prefer plastic products for food packaging.

22. Compare the use of locally available materials such as bamboo, raffia, clay, plywood, and veneer boards with the use of concrete in the building industry.

23. Semi-conductors are widely used in the electronic industry. Identify one product in a local shop or industry in your community that uses semiconductors. Discuss the properties of the semi-conductor in that product that makes it suitable for that product.

24. Discuss the characteristics a material needs to have before it can be used across multiple industries.

25. Compare and contrast the characteristics that make a material fit for use in the automobile and medical industries.

26. You are tasked with the selection of an environmentally friendly material for the packaging of food to expand its shelf life. Propose a material and explain your choice, considering the characteristics of the material.

Answers to Review Questions

1. Materials science plays a crucial role in the development of sustainable solutions such as building materials and solar panels by enabling the design, optimisation, and implementation of materials with improved performance, durability, efficiency, and environmental impact.

   In building materials:

   a. Materials science helps save energy by creating materials that keep buildings warm in the cold and cool in the heat, reducing the need for heating and cooling.

   b. It makes buildings last longer by creating metals that don't rust and plastics that can withstand bad weather.

   c. Materials science develops building materials that can be recycled, reused, or that break down naturally, which helps reduce waste.

   d. It helps lower the carbon footprint of building materials by improving how they are made and using different raw materials.

   In solar panels:

   a. Materials science makes solar panels work better by creating materials that soak up more sunlight and move electricity better.

   b. It makes sure solar panels last a long time by adding coatings that protect them from bad weather and harsh environmental conditions.

   c. Materials science research tries to make solar panels cheaper by improving how they are made and finding cheaper materials to use instead of the usual ones.

2. As a material scientist and material engineer, my role in the research team involves both scientific investigation and practical engineering to develop new materials with specific qualities, abilities and uses. I engage in scientific investigation to understand the fundamental principles governing the behaviour of materials at various length scales, from atomic and molecular structures to macroscopic properties.

   Once new materials are synthesised, my role involves characterising and testing their properties through a variety of techniques. This includes mechanical testing to assess strength and durability, thermal analysis to evaluate thermal conductivity and expansion, electrical measurements to study conductivity and resistivity, and spectroscopic analysis to investigate optical and electronic properties. This also involves identifying efficient processing methods, optimising process parameters, and ensuring reproducibility and quality control to meet industry standards and performance requirements.

   In all, as a material scientist cum material Engineer, my role is to bridge the gap between scientific discovery and engineering application in the development of new materials. By integrating scientific knowledge with engineering principles, I contribute to the advancement of materials technology and the creation of innovative solutions to address societal and technological challenges.

3. Raw material: stone, clay, wood, bamboo, raffia, etc.
   Processed materials: steel, leather, nylon, cement, etc.

4. Material evolution has significantly imparted technological advancement and improved the quality of life. They design and develop materials that have unique properties to meet human needs and new technological trends. For example, the development of materials for medical implants and devices that improve health care; the development of materials to improve the safety and performance of vehicles; the development of flexible electronic materials; and the development of materials that improve the efficiency of energy production and storage systems.

5. Both material science and material engineering are characterised by four main components: processing, structure, properties, and performance. These four components are interrelated. Thus, the structure of a material depends on how it is processed, and material performance is a function of its properties. Material science provides us with a fundamental understanding of the properties, structure, and behaviour of materials. Material engineers leverage their understanding of material properties to design materials that meet specific requirements like strength, durability, and conductivity, depending on the intended applications.

6. The new processing methods for some materials are as follows:
   a. Due to technological advancement, cassava, which used to be processed into fufu with mortar and pistol is now processed with a fufu machine.
   b. Bamboos are now treated before they are used for building structures such as tables and houses.
   c. Clay is now processed using clay grinding machines and shaped using a mechanised potter's wheel, instead of the traditional method of pounding and manually turning the potter's wheel.

7.

Material	Justification/Properties
Raffia	Flexibility
	Water Resistance
	Insulating Properties
	Strength
	Biodegradability

Material	Justification/Properties
Bamboo	Strength
	Durability
	Environmental Benefits
	Flexibility
	Lightweight

8. Processing of engineering materials:
   a. **Wood:** sawing and milling, drying, joinery and assembly, shaping and profiling, finishing.
   b. **Clay:** extraction, preparation, purification, forming (hand building, throwing, extrusion), drying, firing.
   c. **Aluminium sheet:** sheet rolling, cutting, forming and shaping, bending and folding, stamping and punching.
9. Discussion on the effects the process may have on the environment. Focus on activities that reduce the harmful effects of by-products such as improper chemical disposal, emissions, and disposal of scraps.
10. The discussion should focus on the following properties: corrosion resistance, strength and structural integrity, durability in harsh environments, fatigue resistance, and environmental impact.
11. The collapse of the wooden bridge at Esaase Bontefufuo Senior High School could have been influenced by several factors.
    a. **Structure:** The design and construction of the wooden bridge may have contributed to its collapse if it was not properly engineered to withstand the loads and stresses imposed by traffic, environmental factors, and ageing.
    b. **Processing:** The quality of the wood and the processing methods used in its preparation could have affected the strength and durability of the bridge. If the wood was not properly seasoned, treated, or inspected for defects such as knots, cracks, or decay, it may have been prone to premature failure.
    c. **Properties:** The inherent properties of the wood, such as its strength, stiffness, moisture content, and resistance to decay, would have influenced the performance of the bridge.

    Overloading vehicles, extreme weather, and constant exposure to moisture and salt from the river could have weakened the wood, causing the bridge to collapse. Using materials like structural steel or reinforced concrete for rebuilding the bridge can provide better strength, durability, and safety than wood.

12. Understanding the structure, processing, properties, and performance of materials helps consumers choose products that work well. For example, picking cookware with good heat conductivity and non-stick properties makes cooking easier and more efficient. Choosing materials that meet specific needs, like thermal insulation, moisture resistance, or impact resistance, ensures products will perform effectively.

13. For products used in high-temperature environments, like gas turbine engine parts or heat exchangers, the chosen material must have specific properties to perform well. These properties include high-temperature strength, excellent corrosion resistance, thermal stability, fatigue resistance, and thermal conductivity. Nickel-based super-alloys are ideal for these applications due to their strength, stability, and corrosion resistance, making them essential for industries with extreme operating temperatures.

14. Materials used along the coast need to withstand the unique environmental conditions, such as corrosion, weather, and saltwater. Important properties include corrosion resistance, weather resistance, durability, low maintenance, and environmental compatibility. Materials like stainless steel, marine-grade aluminium, fibre-reinforced composites, treated woods, and synthetic polymers are suitable for coastal use because they resist corrosion and saltwater exposure, ensuring the longevity and safety of coastal structures.

15. **B–Copper:** Copper is a metal and has a high electrical conductivity as compared to rubber and Kevlar which are non-metals and have insulating properties. Silicon has intermediate properties between insulators and electrical conductors.

16. **Carbon Fibre Reinforced Polymer (CFRP):** They are light in weight and have high strength properties.

17. Metals have a high melting point as compared to the low melting point of plastic. The plastic will melt faster than the metal. Metals have high thermal conductivity and will therefore transmit the heat from the end exposed to the fire to your hand. In contrast, the plastic bottle will feel cold on the end not exposed to the heat.

18. Non-metals such as plastics and rubber materials are recommended due to their high insulating properties and will therefore protect the electrician from electrical shocks.

19. Aluminium and magnesium alloys offer a compelling combination of lightweight, strength, corrosion resistance, fatigue resistance, and cost-effectiveness, making them well-suited for manufacturing aircraft components. Their properties meet the demanding requirements of aerospace applications, where performance, reliability, and efficiency are paramount.

20. Stainless steel is preferred in the food industry rather than in the clothing industry due to the following reasons:

    a. Stainless steel is non-reactive to food substances; it has a non-porous surface, making it easy to clean and resistant to bacteria build-up. This is crucial in environments such as food processing plants and commercial kitchens. This is a particularly important requirement in the food industry, where cleanliness is paramount. Material selection for maintaining the integrity and quality of food products cannot be overemphasised.

21. Despite the environmental challenges posed by plastics, they are widely used in the food industry for packaging due to their convenience and cost-effectiveness. Plastic packaging is lightweight and easy to handle, providing convenience for both manufacturers and consumers. Additionally, plastics are relatively inexpensive to produce, rendering them an economically viable choice for packaging food products.

22. When comparing locally available materials such as bamboo, raffia, clay, plywood, and veneer boards to concrete, the former are more environmentally friendly and offer a distinctive aesthetic appearance. Concrete production involves considerable energy consumption and indirectly releases a significant amount of carbon dioxide, contributing to greenhouse gas emissions. Nonetheless, concrete is known for its strength and durability, making it suitable for a wide range of structural applications, including high-rise buildings, bridges, and infrastructure.

23. The unique properties inherent in semiconductors, such as conductivity, band-gap doping, temperature dependence, and switching speed, make them useful for a wide range of electronic applications like diodes, transistors, integrated circuits, and microprocessors.

24. Materials suitable for use across multiple industries should possess unique properties and characteristics that make them versatile, reliable, and suitable for various applications. They should be materials that are adaptable to different manufacturing processes, making them suitable and applicable in different industries. Such materials should possess mechanical properties that make them reliable under varying conditions in different industrial settings.

25.

a. **Strength and Durability:** Materials used in the automobile industry need to withstand impacts, vibrations, and mechanical stresses during operation. In the medical industry, materials mostly used should be durable enough to withstand mechanical actions or impacts during use. The material should mimic the tissues in contact with medical devices.

b. **Weight:** In the automobile industry, lightweight materials are preferable since they improve fuel efficiency and performance. The medical industry also requires lightweight materials since they enhance the usability and comfort of medical devices, especially those worn by patients for extended periods.

c. **Regulatory compliance:** Both the automobile and the medical industries adhere to industry-specific regulations and standards to ensure the safety, efficiency, and legal use of materials.

d. **Corrosion Resistance:** The effect of corrosion in the automobile industry has always been a challenge; hence, materials selected should possess high resistance to corrosion so that components can last longer. In the medical industry, corrosion resistance is a major factor, especially for devices that come into contact with bodily fluids.

26. One unique environmentally friendly material for the packaging of food to extend its shelf life is polylactic acid (PLA). Polylactic acid (PLA) is a biodegradable and compostable bio-based plastic or thermoplastic polymer derived from renewable resources such as corn starch, sugarcane, or other plant sources.

    In industries where sustainability is a priority, such as packaging, textiles, and biomedical devices, PLA becomes the best alternative to our traditional petroleum-based plastics because it offers unique properties such as:

    a. **Biodegradability** means a material can easily break down into carbon dioxide and water under composting conditions, making it environmentally friendly and reducing reliance on finite fossil fuels.
    b. **Compatibility with food:** PLA is considered safe for food contact and is approved by regulatory agencies such as the FDA for use in food packaging applications. It does not leach harmful chemicals into food, ensuring consumer safety.
    c. **Mechanical properties:** These include stiffness and tensile strength, making it suitable for applications where structural integrity is important.

Extended Reading

1. Callister, W. D., & Rethwisch, D. G., (2020). Materials Science and Engineering: An Introduction, 9th Edition, John Wiley & Sons. Chapters 13 and 15.
2. Tiwari, A., Murugan, N. A., & Ahuja, R. (2016). Advanced Engineering Materials and Modeling. John Wiley & Sons.
3. Mikell P. Groover, (2010). Fundamentals of Modern Manufacturing. Materials, Processes, and Systems.

Acknowledgements

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